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# Wireless Communications

EENG 5820

Lecture 7

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# 5.4 Parameters of Mobile Multipath Channels

## ■ Time dispersion parameters

$$h_b(t, \tau) = \sum_{i=0}^{N-1} a_i(t, \tau) \exp[j(2\pi f_c \tau_i(t) + \phi_i(t, \tau))] \delta(\tau - \tau_i(t))$$

Mean excess delay

$$\tilde{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k) \tau_k}{\sum_k P(\tau_k)}$$

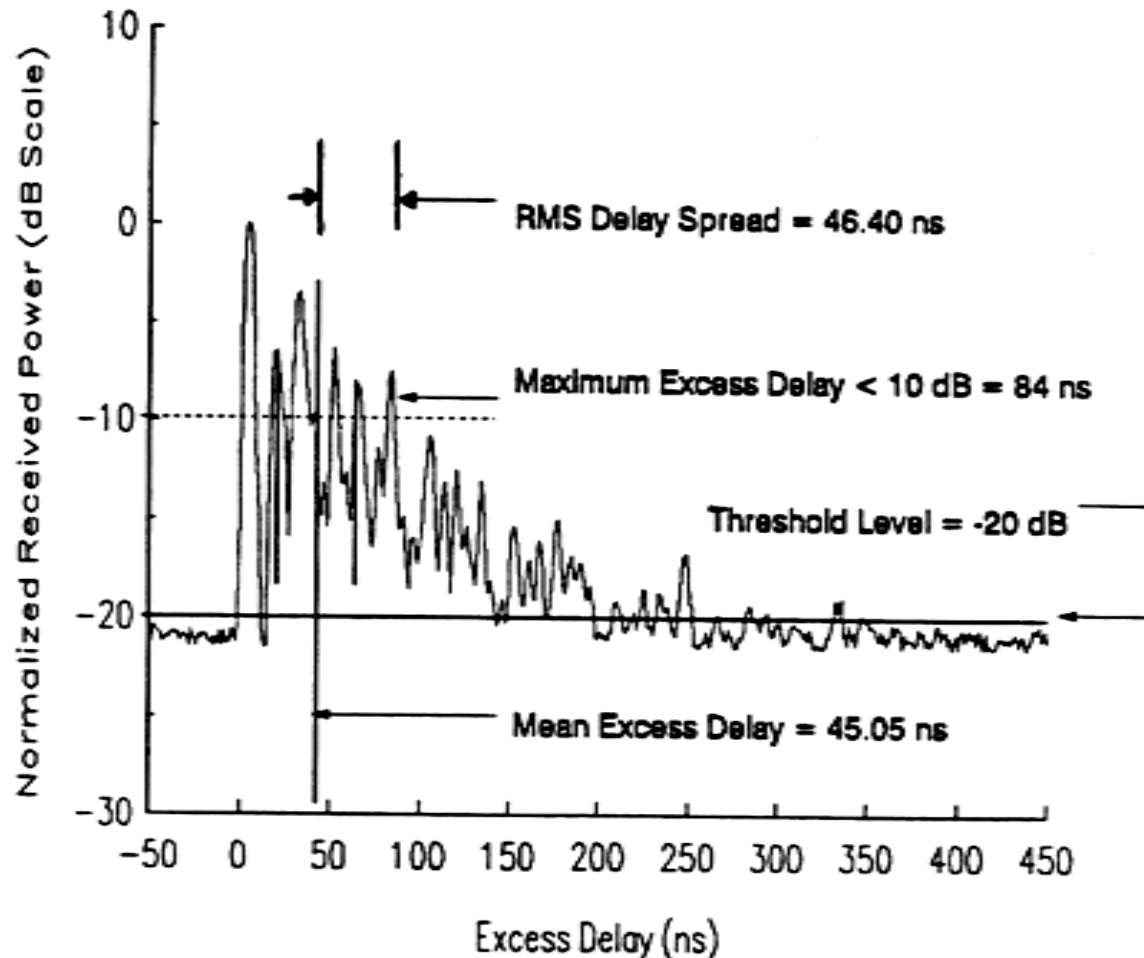
rms excess delay

$$\sigma_\tau = \sqrt{\bar{\tau}^2 - (\tilde{\tau})^2}$$

$$\bar{\tau}^2 = \frac{\sum_k a_k^2 (\tau_k)^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k) (\tau_k)^2}{\sum_k P(\tau_k)}$$

**Maximum excess delay (dB):**  $\tau_X - \tau_0$ : within X dB of the **strongest** arriving path signal

## 5.4.1 Time Dispersion Parameters



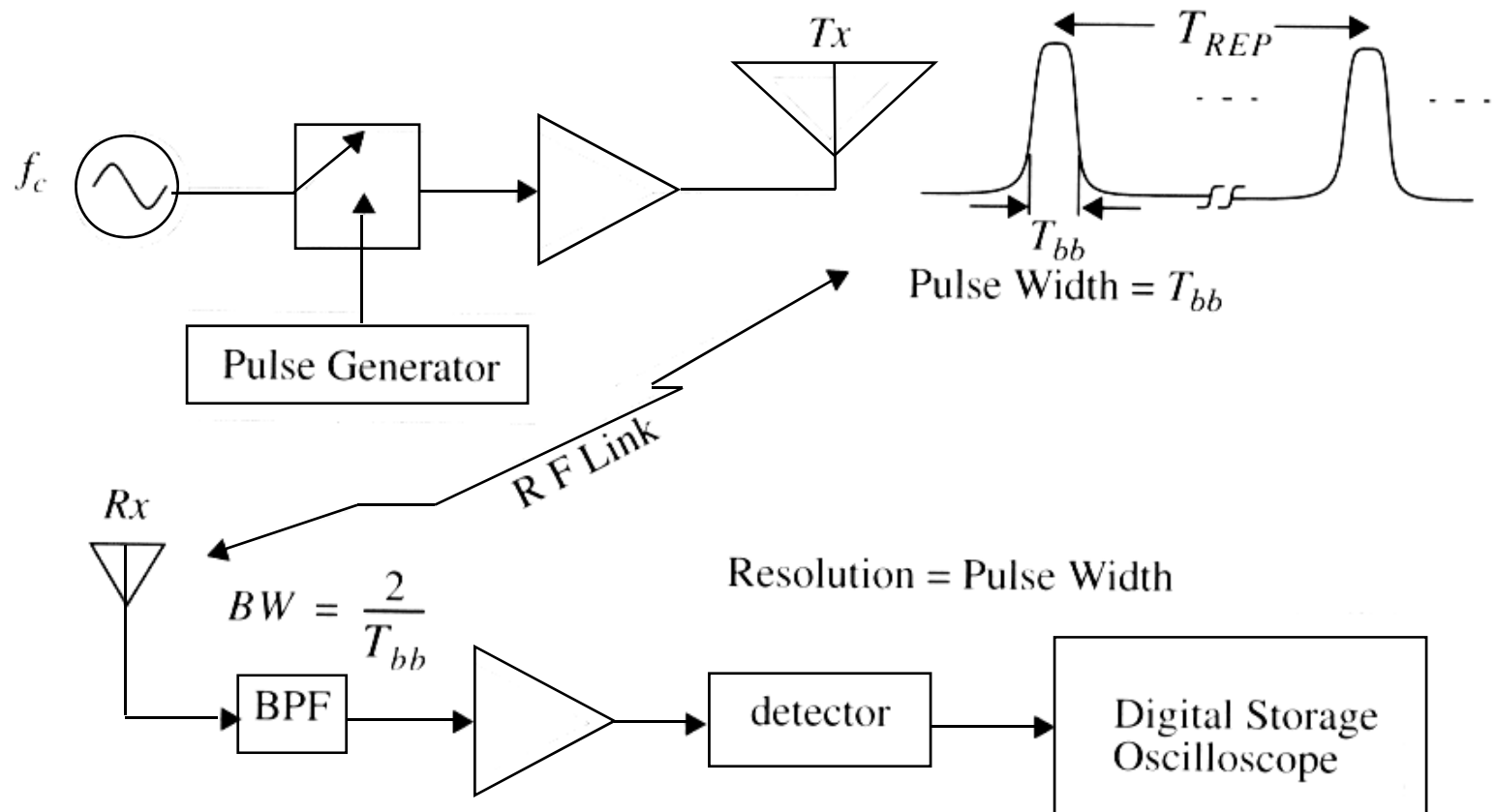
**Figure 5.10** Example of an indoor power delay profile; rms delay spread, mean excess delay, maximum excess delay (10 dB), and threshold level are shown.

## 5.4.1 Time Dispersion Parameters

**Table 5.1** Typical Measured Values of RMS Delay Spread

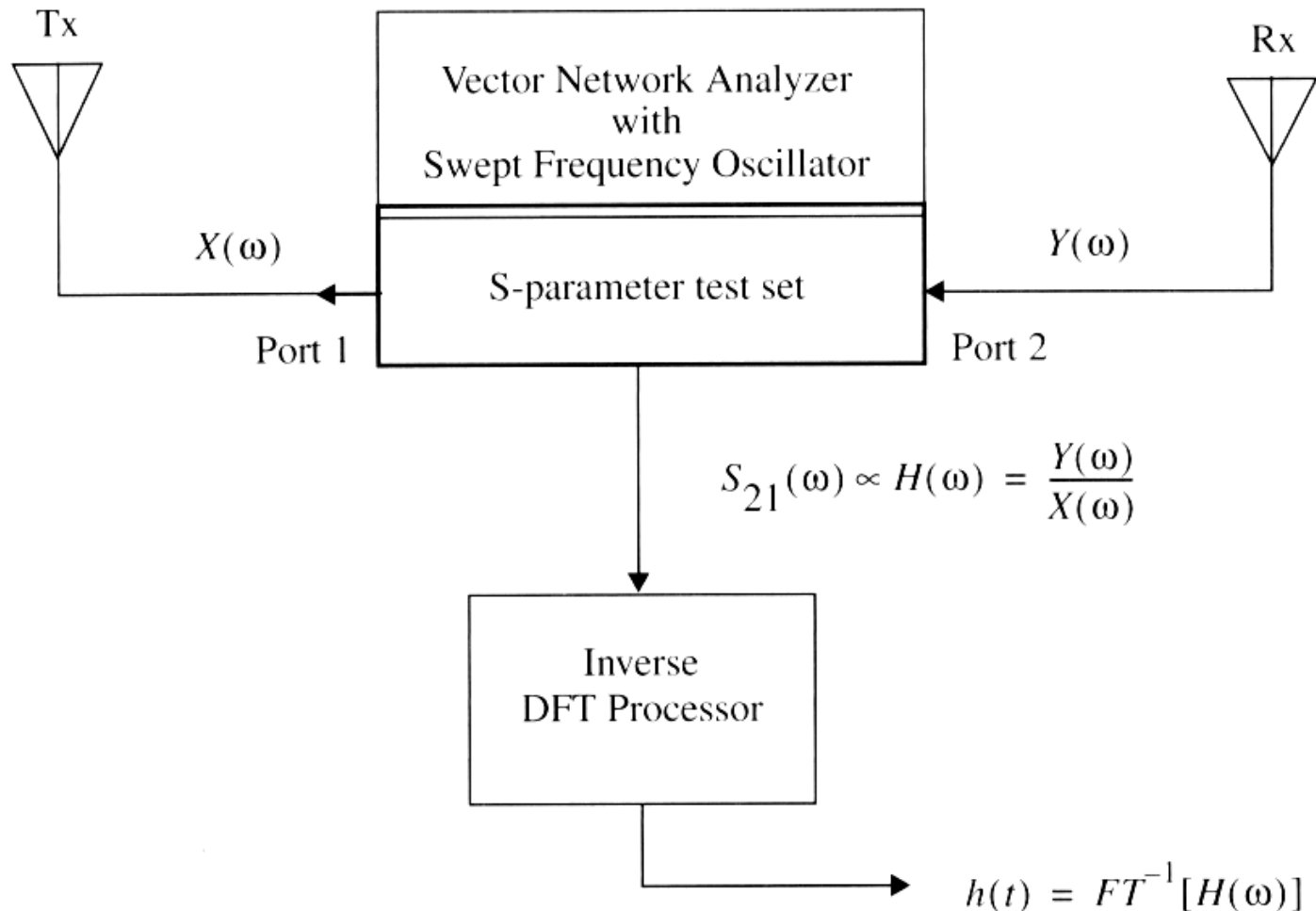
Environment	Frequency (MHz)	RMS Delay Spread ( $\sigma_\tau$ )	Notes	Reference
Urban	910	1300 ns avg. 600 ns st. dev. 3500 ns max.	New York City	[Cox75]
Urban	892	10–25 $\mu$ s	Worst case San Francisco	[Rap90]
Suburban	910	200–310 ns	Averaged typical case	[Cox72]
Suburban	910	1960–2110 ns	Averaged extreme case	[Cox72]
Indoor	1500	10–50 ns 25 ns median	Office building	[Sal87]
Indoor	850	270 ns max.	Office building	[Dev90a]
Indoor	1900	70–94 ns avg. 1470 ns max.	Three San Francisco buildings	[Sei92a]

## 5.3.1 Direct RF Pulse System



**Figure 5.6** Direct RF channel impulse response measurement system.

## 5.3.3 Frequency Domain Channel Sounding



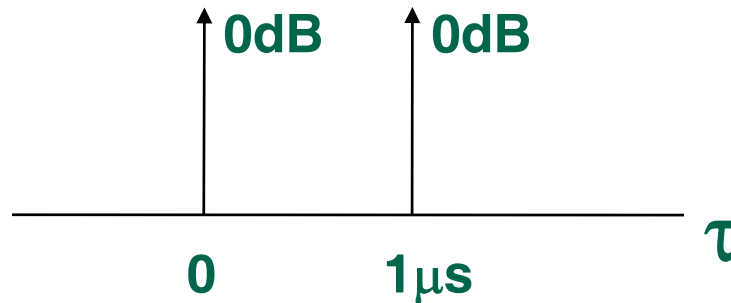
**Figure 5.8** Frequency domain channel impulse response measurement system.

# 5.4.1 Time Dispersion Parameters

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## Example 5.4

a) Compute RMS delay



## 5.4.2 Coherence Bandwidth

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- **Coherence bandwidth: a statistical measure of the range of frequencies over which the channel can be considered as “flat” (equal gain and linear phase)**
- **Frequency correlation = 0.9:  $1/(50\sigma_\tau)$**
- **Frequency correlation = 0.5:  $1/(5\sigma_\tau)$**

## 5.4.3 Doppler Spread and Coherence Time

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### ■ Doppler Spread $B_D$

$$f_d \equiv \frac{1}{2\pi} \frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda} \cos \theta = B_D$$

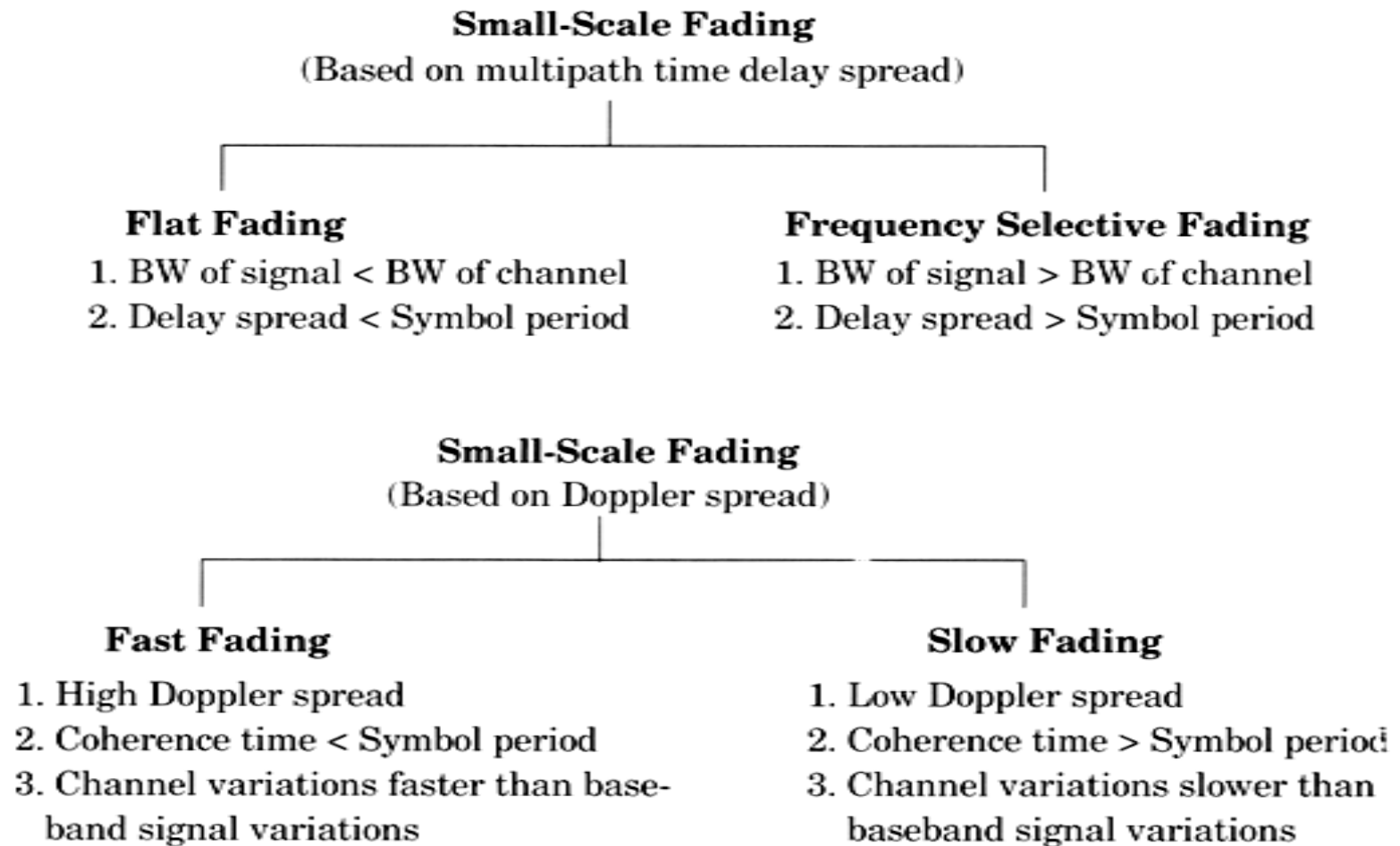
### ■ Coherence Time: $T_c$

- Measure of length of time that channel impulse response is almost invariant

### ■ For a time correlation of 0.5

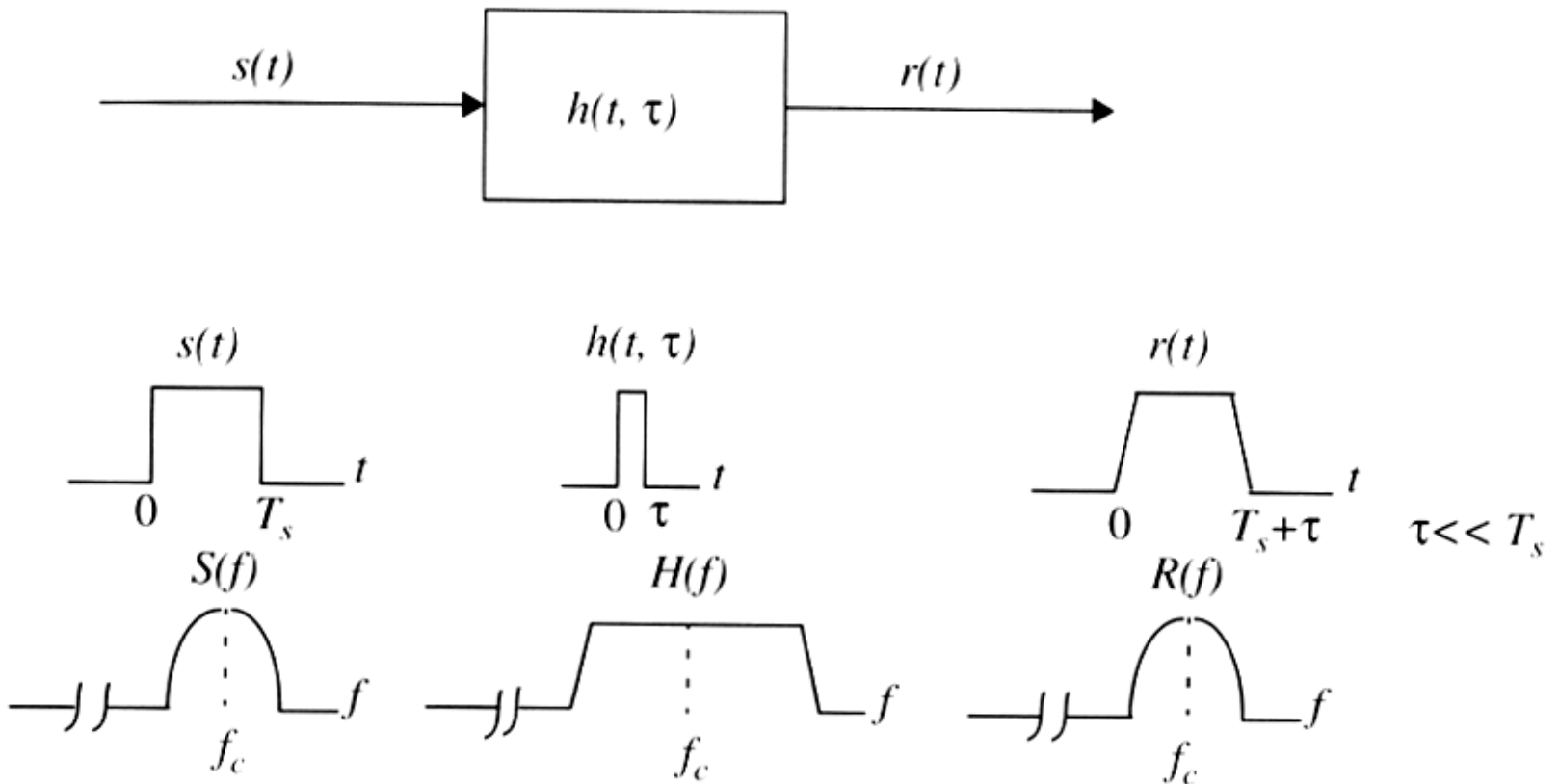
$$T_c \cong \frac{9}{16\pi f_m}$$

# 5.5 Types of Small-Scale Fading



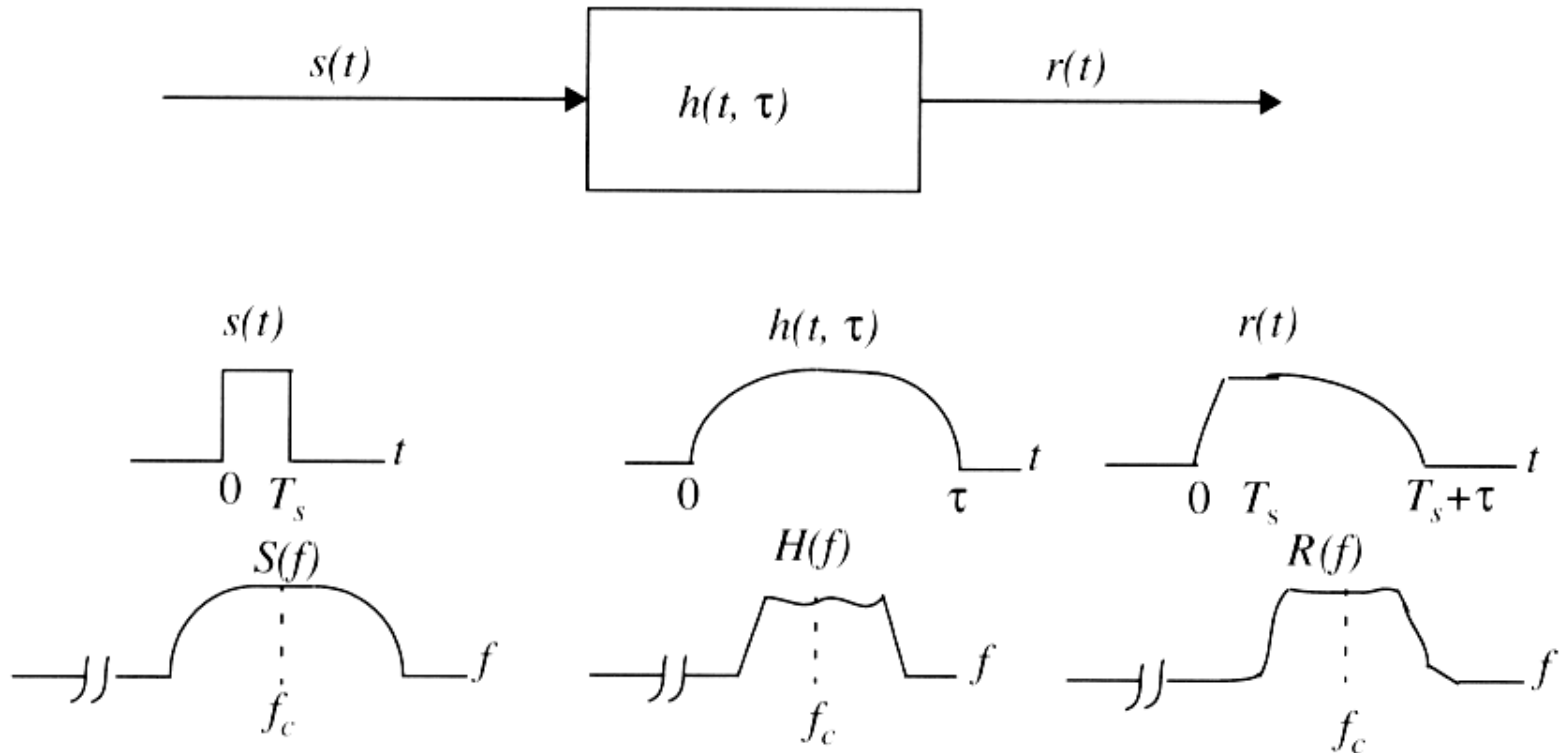
**Figure 5.11** Types of small-scale fading.

## 5.5 Types of Small-Scale Fading



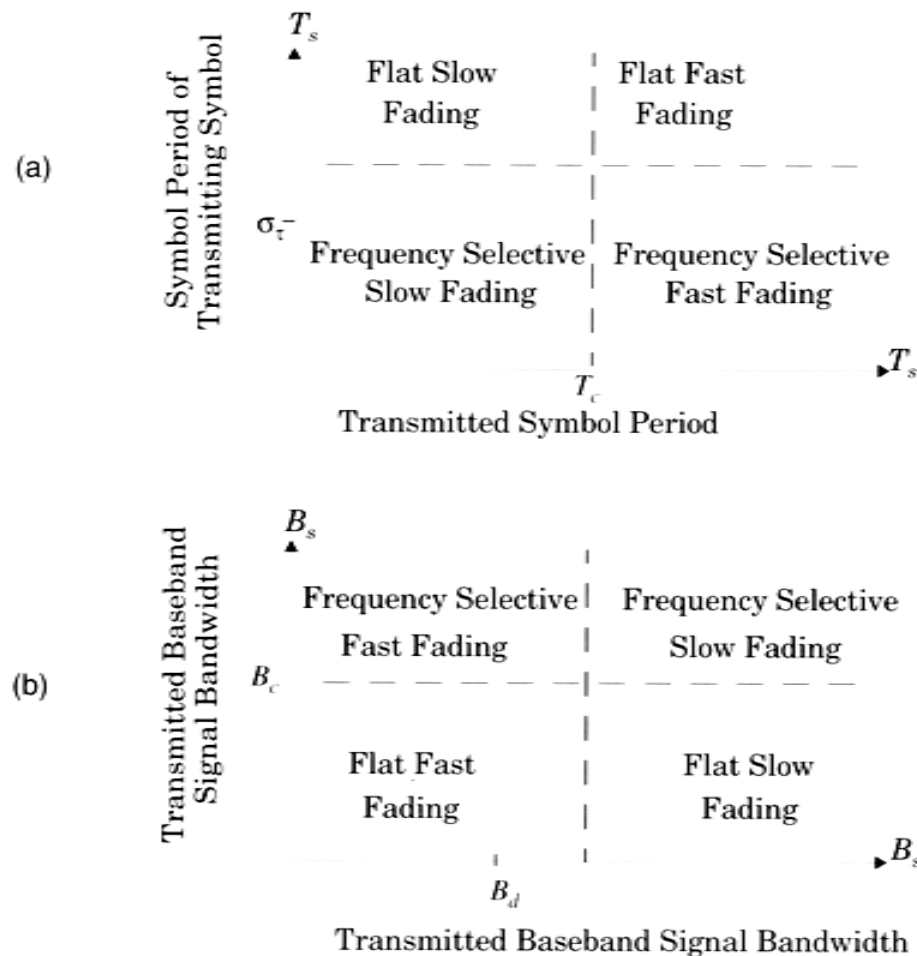
**Figure 5.12** Flat fading channel characteristics.

## 5.5 Types of Small-Scale Fading



**Figure 5.13** Frequency selective fading channel characteristics.

# 5.5 Types of Small-Scale Fading



**Figure 5.14** Matrix illustrating type of fading experienced by a signal as a function of: (a) symbol period; and (b) baseband signal bandwidth.

# Homework

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- 5.1, 5.2, 5.5, 5.6, 5.16, 5.27, 5.28